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# SPACE STATION *FREEDOM* TOXICOLOGY AND ENVIRONMENTAL MONITORING

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MONITORING

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Sponsored by  
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Houston, TX 77058  
September 18-20, 1989

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SECTION 2  
AGENDA

SPACE STATION FREEDOM  
TOXICOLOGY WORKING GROUP MEETING  
SEPTEMBER 18-20, 1989

**Monday, September 18**

8:00 a.m.	Welcome to Johnson Space Center	C. Huntoon
	Introductions	
8:10	Overview of Space Station Freedom (SSF)	J. Robinson
8:30	Physiological Effects of Spaceflight	J. Davis
8:50	Sources of Airborne Contaminants	J. James
9:10	Control of Materials Offgassing on SSF	M. Pedley
9:30	Environmental Control and Life Support System (ECLSS)-- Air Revitalization	J. Perry
10:15	Break	
10:30	Suggested Chemicals to be Monitored	K. Wong
11:00	Tour of SSF and Space Shuttle Orbiter Mockups	
12:30 p.m.	Lunch	
2:00	Spacecraft Maximum Allowable Concentrations (SMACs)	M. Coleman
2:30	Overview of Toxicology Plan	T. Limero
2:45	Contingency Scenarios Involving a Toxic Chemical Release	J. Heitzman
3:10	Monitoring Hardware	T. Limero
4:00	Human Factors	R. Springer
4:30	Discussion of Issues	

**Tuesday, September 19**

8:00 a.m.	Formation of Toxicology and Sampling/Monitoring Splinter Groups	
11:30	Lunch	
1:00 p.m.	Splinter Groups Reconvene	
4:30	Splinter Groups Conclude Their Discussions	

**Wednesday, September 20**

8:00	Toxicology Splinter Group Summary	
8:30	Sampling/Monitoring Splinter Group Summary	
9:00	Full Working Group Interaction to Meet Conference Objectives	
12:00 p.m.	Working Lunch	
2:00	Conclusion of Meeting	

## Section 3

### PANEL REPORT

#### 3.1 SUMMARY

The Space Station Freedom (SSF) Toxicology Panel met to make recommendations to NASA on issues related to the environmental monitoring program for Space Station Freedom. The panel addressed both nominal and contingency airborne contamination scenarios. The panel consisted of experts in toxicology, analytical and environmental chemistry, and industrial hygiene.

Panel recommendations can be divided into three main areas:

1. Setting of exposure limits for chemical contaminants
2. Risk reduction and countermeasures
3. Sampling and monitoring strategy

##### 3.1.1 Exposure Limits

In terms of setting spacecraft maximum allowable concentrations (SMACs) for airborne contaminants, the panel considered the unknown effect of microgravity on susceptibility to be of more concern than differences in toxic effects from continuous exposures when compared to intermittent exposures. The "T" value approach, which is currently used for evaluating mixtures of contaminants within toxicity groups, was considered appropriate although definition of those groups should be reconsidered. The NRC 90-day Continuous Exposure Guidance Levels (CEGLs) prepared for submarine operations may be useful as a starting point for setting some 180-day SMACs.

If a contingency situation develops as a result of a chemical release into the SSF internal atmosphere, emergency maximum exposure concentrations (EMACs) will be used to aid in making critical decisions. The

panel recommended a number of ways to formulate EMACs which should be established for exposure times of 15 minutes to 24 hours.

### 3.1.2 Risk Reduction and Countermeasures

The panel strongly emphasized the role of prevention to minimize the probability of a contingency. Prevention strategies should include the following: toxicity of thermodegradation products as a criterion for acceptance of a material, risk-benefit analysis on payload experiments involving chemicals, substitution of less toxic compounds where possible, and high fidelity testing of offgassed products and flow patterns. Astronauts must be given thorough training related to hazardous chemical payloads so that they are prepared to recognize, control and protect themselves from an accidental release.

General recommendations were given for protective equipment and decontamination strategies. Personal protective equipment, such as goggles, gloves and laboratory aprons, must be worn when a potentially hazardous activity is in progress. In addition, individualized protective masks with interchangeable, chemical-specific canisters, must be immediately available during high-risk activities. Contingency planning and procedures must be established for large-scale removal of volatile and particulate materials from contaminated areas.

### 3.1.3 Sampling and Monitoring Strategy

The panel emphasized that a clear understanding of the intra- and intermodule airflow patterns within SSF will be required to develop an adequate sampling and monitoring strategy. Moreover, during the early



operation of SSF, one crewmember should be trained in environmental monitoring, and an earth downlink should be provided for data from inflight monitoring instrumentation. Downlinking was considered particularly important for contingency situations.

Both portable and fixed instrumentation are needed for nominal and contingency operations. During nominal operations, both real-time continuous monitoring and periodic monitoring of the internal atmosphere are needed. Gaseous contaminants that should be considered for air monitoring include  $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{H}_2$ ,  $\text{CH}_4$ ,  $\text{HCN}$ ,  $\text{HCl}$ ,  $\text{HF}$ ,  $\text{COF}_2$  (possibly  $\text{NO}_x$  and  $\text{SO}_x$ ), and volatile organic compounds. In addition, a particulate monitor with size discrimination should be available. The panel also recommended payload-specific monitoring of all potentially hazardous experiments, such as those involving toxic metals, unless the level of containment is such that the potential for toxic release is minimal. Finally, the panel recommended technologies that should be considered and evaluated for active, passive, and archival air sampling, and monitoring instrumentation.

### 3.2 INTRODUCTION

The Space Station Freedom Toxicology Panel was convened to review issues related to airborne contamination caused by materials offgassing, routine activities, and accidental release. Both volatile and particulate contaminants were discussed in terms of their impact on crew health and in terms of monitoring strategies. The panel members included inhalation and environmental toxicologists (Drs. Pier, Lewis, Gardner, Dahl and Graham),

analytical and environmental chemists (Drs. Pellizzari, Overton and Giam), and environmental health specialists (Drs. Stock, Colome and Marple).

The panel met for 3 days (September 18-20, 1989), at the Nassau Bay Hilton Hotel adjacent to the Johnson Space Center. Previous conferences related to this subject include "Airborne Particulate Matter in Spacecraft," which was held on July 23-24, 1987, and "Space Station Toxicology," which was held on December 3-4, 1985. Relevant background information on the environmental health program for SSF was sent to panel members prior to the conference.

The first day of the conference included informational presentations of key issues concerning the program and its operational constraints, including the physiological effects of space flight, the Environmental Control and Life Support System (ECLSS), offgassing and thermodegradation toxicology, sampling and monitoring plans, and human factors. The first day also included a tour of the Shuttle and Space Station mockups. On the second day, panel members were separated into two splinter groups; one group discussed inhalation toxicology issues, and the other focused on airborne contaminant monitoring. On the last day, the full panel was reconvened to compare findings and to formulate a consensus from deliberations in the splinter groups. In general, there were few areas where the splinter groups had significantly different recommendations. The present report summarizes conclusions from both splinter groups without identifying the source of the conclusion. It must be noted that the findings were based only on information presented to the panel and voiced during splinter group deliberations.

### 3.3 EXPOSURE LIMITS

#### 3.3.1 Long-term Intermittent vs. Long-term Continuous Exposures

NASA toxicologists have voiced concern over the continuous long-term exposure of Space Station crewmembers, since SMACs are generally based on data from long-term intermittent exposures to workers or test animals. Limited data are available to compare the toxic effects induced by intermittent vs. continuous inhalation exposures. The panel recommended that such comparisons probably would not be useful for respiratory system irritants; however, comparisons for compounds with other mechanisms of toxicity (e.g. CNS depressants, carcinogens, hepatotoxins) may prove useful when setting long-term SMACs. It was noted that possible effects of microgravity on susceptibility to airborne contaminants may be of greater interest.

#### 3.3.2 Effect of Combined Exposures to Airborne Contaminants

The current practice is to estimate the potential for toxic effects from combined exposures to toxic compounds by calculating a "T" value defined as follows:

$$T = \sum_{i=1}^n C_i / \text{SMAC}_i$$

where  $C_i$  and  $\text{SMAC}_i$  are the concentration and SMAC of the  $i$ th component, respectively, and  $n$  is the number of chemicals in the toxicity category. A  $T$  value is calculated for each major category of toxic action. If  $T \geq 1$  for a given category, then actions would be taken to reduce the exposure. The panel recommended that the categories for which  $T$  values are calculated be changed to those used by the Occupational Safety and Health Administration (OSHA).

### **3.3.3 Use of NRC 90-Day Continuous Exposure Guidance Levels (CEGL)**

The National Research Council (NRC) has established 90-day CEGLs for submarine operations. The panel felt that NASA toxicologists should be able to adjust these values to account for mission duration and physiological effects of microgravity to estimate SMACs for missions of 30-180 days. The panel further recommended that preliminary SMACs be reviewed by experts outside NASA before they are formally adopted.

### **3.3.4 Effect of Exercise on Susceptibility to Contaminants**

Although specific data were not available to the panel, the general consensus was that the immediate physiological changes that occur during exercise of 2 hours duration probably would not affect acceptable concentration limits. However, during contingency periods, it is possible that cabin contamination might be too high for vigorous exercise. For a more definitive conclusion, the panel recommended that NASA toxicologists obtain data from the exercise physiology group and evaluate the magnitude of the increased risk.

### **3.3.5 Emergency Maximum Exposure Concentrations (EMACs)**

An EMAC defines the maximal time that a contaminated module can be occupied by an unprotected astronaut. The panel recommended that no payload experiment be flown until instruments are available to measure accidental release of hazardous chemicals at levels below the EMAC. However, if extreme containment substantially reduces the potential for hazardous release, then payload-specific monitoring may not be required. The most useful EMACs would be for durations of 15 minutes, 60 minutes, and 24 hours.

Some of these could be based on emergency exposure guidance levels (EEGLs) or short-term exposure limits (STELs); however, each chemical must be dealt with on an individual basis with a knowledge of how much performance decrement could be accepted. Other sources of information are the German MAKs and the immediately dangerous to life or health (IDLH) levels. The latter would be scaled down significantly to provide realistic EMACs. The panel suggested that EMACs could be used to limit the quantity of a potentially hazardous material brought aboard SSF.

### **3.4 RISK REDUCTION AND COUNTERMEASURES**

#### **3.4.1 Toxicity of Thermodegradation Products as a Criterion for Flight Certification**

The panel recommended that the toxicity of thermodegradation products of a given material be considered prior to flight certification. Use of a material with known toxic pyrolysis products may be necessary due to other priorities; however, when such materials must be used, the toxicity and chemical components after pyrolysis should be well characterized. This information will aid in making decisions on monitoring requirements and interpretation of data should the material undergo thermodegradation in a spacecraft.

#### **3.4.2 Chemical Interactions of Airborne Contaminants**

Under some conditions, chemical reactions of a contaminant with another contaminant or with hardware can result in damage to hardware, or generation of a more toxic species. An example of the former is fouling of electrical contacts by siloxanes. It was recommended that an atmospheric

chemist examine the list of potential contaminants to determine whether chemical reactions could pose a problem. Because chemicals could be concentrated in the scrubber system, conversions may occur there; however, this appears very unlikely due to the redundancy in the ECLSS.

#### **3.4.3 Risk-Benefit Analysis**

All payload experiments involving potentially hazardous materials should be subjected to a formal risk-benefit analysis. Part of this analysis could include modeling of accident scenarios related to the hazardous material. Chemists and industrial hygienists should be involved in the analysis process.

#### **3.4.4 Compound Substitution**

In some payload experiments it may be feasible to substitute less toxic compounds in place of toxic chemicals. For example, for most applications toluene would be a less toxic substitute for benzene. Investigators proposing payload experiments should be encouraged by guidelines to identify possible chemical substitutions that would reduce potential chemical hazards.

#### **3.4.5 Astronaut Screening**

Under special circumstances it may be advisable to screen astronauts for hypersensitivity to payload chemicals. For example, certain metals and proteins are potent sensitizers and these could present an unexpected hazard if a sensitized individual were exposed in an environment where medical treatment is limited.

#### **3.4.6 Fidelity of Testing**

The panel recommended that offgassing studies and air flow evaluations be performed on SSF mockups. The mockups should be studied at the highest fidelity possible to minimize unexpected airborne toxicity problems aboard SSF. Prior to assembly of SSF, the offgassing of individual components should be evaluated for an appropriate period of time. The panel emphasized the collection of as much preflight data as possible to better predict the SSF atmospheric contaminants, and to understand clearly the atmospheric dynamics.

#### **3.4.7 Hazard Communication to Astronauts**

The panel recommended that when potentially hazardous payloads are to be handled in spacecraft, the astronauts should receive a 1 hour safety briefing that includes ways to recognize an accidental release, control the release, and protect themselves from exposure to the airborne hazard. This briefing was recommended not only for SSF, but for current operations involving Spacelab and the STS.

#### **3.4.8 Personal Protective Equipment**

Crewmembers conducting experiments involving potentially hazardous compounds should have immediate access to protective equipment during experiments. Each crewmember should have an individually-fitted mask with interchangeable canisters to protect against specific hazardous compounds. A very wide spectrum of protection can be provided from only 3 types of canisters, which could be interchanged according to the potential hazards from specific experiments.

#### **3.4.9 Decontamination**

The panel expressed deep concern about the lack of adequate capability to decontaminate after a significant release of hazardous chemical. The panel considered the current limited depressurization/repressurization strategy insufficient. The panel recommended that a large-scale emergency decontamination system be available in the event of a chemical release or thermodegradation incident that exceeds the capabilities of the normal trace-contaminant control system. This decontamination system should be able to reach various places in each module so that the decontamination effort may be focused. Suggested technologies included a sorbent system or extravehicular cold trap for removing volatile compounds from air. A separate emergency system should also be available for accidental release of particulates. There must be a separate filter or removal device for large particles, which tend to obstruct removal devices for small particles. Thermophoresis was suggested as a possible method for filtering small particles.

### **3.5 SAMPLING AND MONITORING STRATEGY**

#### **3.5.1 Ventilation Studies**

The panel emphasized that a clear understanding of the intra- and intermodule airflow patterns within SSF is needed to develop an adequate sampling and monitoring strategy. The panel recommended full-configuration, ground-based studies of the ventilation rates and airflow velocities within SSF. Modeling of the airflow patterns will aid in determining:



1. Sampling locations to adequately characterize the atmosphere in a module or node.
2. The spread of a contaminant after it is released from a point source.
3. Areas where ventilation is poor, resulting in contamination "hotspots".
4. Scrubbing efficiency for model contaminants

### 3.5.2 Sampling Methods

The panel recommended that both fixed and portable instrumentation be available for nominal and contingency operations. During nominal periods, the panel emphasized that crew involvement with sampling and monitoring hardware should be minimal. However, during contingency situations, active involvement of the crew through use of portable instrumentation for contaminant monitoring may be required.

The need for flexibility in methods of sample collection was emphasized. During nominal and contingency periods, sample lines could be used for certain contaminants to provide a remote sampling capability; however, the panel recognized that potential problems, such as adsorption of analytes, could occur unless the lines are designed specifically for the contaminants to be measured. Passive sampling, both area and personal, should be considered for inflight and ground-based analyses of certain contaminants. The consensus among panel members was that personal sampling could be limited to contingency periods and high-risk activities unless airflow testing indicates a heterogeneous atmosphere will be present on SSF. During contingency periods or investigations, the panel recommended that evacuated

canisters be provided for the collection of "grab" samples for the analysis of volatile organic compounds.

### 3.5.3 Monitoring Plan During Nominal Periods

During nominal periods, the panel recommended routine monitoring for the following: total hydrocarbons, volatile organic compounds, major atmospheric gases, nonspecific particulate mass, and specific compounds that are of special concern.

#### 3.5.3.1 Continuous Monitoring

##### Total Hydrocarbons

Monitoring of total and atmospheric hydrocarbon content will be useful for determining when major perturbations have occurred in the overall organic loading in the internal atmosphere. Thus, a total hydrocarbon analyzer operating continuously will serve as a "first alert" system for volatile organic contamination from a chemical leak or spill.

##### Major Atmospheric Gases

The panel recommended that atmospheric gases including  $N_2$ ,  $O_2$ ,  $CO_2$ ,  $H_2$ ,  $H_2O$  and  $CH_4$  be monitored on a routine basis. The panel agreed that rapid analysis using mass spectrometry would be appropriate.

##### Compounds of Special Concern

The panel also recommended continuous measurement of  $CO$ ,  $HCN$ ,  $HCl$ ,  $HF$  and  $COF_2$  to provide crewmembers with a "first alert" of a thermodegradation event. One or more of these compounds would serve as an indicator that an incident has occurred, and aid in determining the quality of the atmosphere

for reentry into a contaminated area. Some panel members considered monitoring of  $\text{NO}_x$  and  $\text{SO}_x$  important; however, a consensus was not reached for these compounds because it was not clear whether exposures are likely.

#### 3.5.3.2 Periodic Monitoring

##### Volatile Organic Compounds

The panel recommended periodic sampling of the internal atmosphere for volatile organic compounds. Onboard qualitative and quantitative analysis for atmospheric characterization is necessary. Analysis should be conducted daily, and provisions should be made, for more rapid analysis (within a few hours) if an instrument must be used to analyze air following an accidental release of contaminants.

##### Nonspecific Particulate Mass

The panel recommended that the particulate content of the internal atmosphere be measured on a periodic basis. Particulate analyzers should provide real-time data and be capable of size discrimination.

#### 3.5.4 Monitoring Plan During Contingency Periods

There was considerable discussion on contingency operations after a chemical release or thermodegradation incident. In both cases, flexibility in the use of the instrumentation and rapid analysis were considered highly desirable. Rapid analysis and portable operating capabilities for instrumentation specific to the compounds mentioned in section 3.5.3.1 were recommended. In addition, before reentering an isolated area after an incident, an air sample should be analyzed for volatile organic compounds by either

remote sampling using sampling lines or with a portable sampler. A volatile organic analyzer, in conjunction with compound-specific instrumentation, would be required to confirm that a contaminated area is safe for reentry. The particulate monitor, used during nominal periods, should be portable; this monitor should be used in the event of smoke generation or accidental release of particulates. A portable total-hydrocarbon analyzer could be useful in locating sources of leaks of volatile organic compounds.

### 3.5.5 Classes of Contaminants of High Concern

In addition to compounds discussed above, three classes of airborne contaminants were also considered to pose potential hazards to crew health: particulates, airborne metallic compounds, and biological contaminants from payload experiments.

Particulates were of concern primarily because of the lack of data on their size distribution, mass, and chemical composition. Particle-bound chemicals were the subject of considerable discussion by the panel. Water-soluble chemicals that are generally scrubbed by the upper airways may be carried deep within the respiratory system when bound to small particles. When deposited in the distal respiratory system, these chemicals may be significantly more toxic if their bioavailability is high. Because there are very limited data on the size distribution and quantity of particles on space flights, it was difficult to reach a firm conclusion on this issue. Although the panel generally agreed that this may not be a problem, new particle data such as that anticipated from STS-32 may suggest that more attention be focused in this area.

Airborne metallic compounds were of concern because of anticipated heavy use and high toxicity in some cases. However, the panel recognized the lack of current technology for monitoring these compounds with instruments compatible with SSF operational constraints. The panel recommended redundant containment as the best solution at this time. Priorities for developing containment and monitoring strategies will evolve with better definition of payload experiments. Finally, compounds from biological sources being used in payload experiments may present unique hazards because of their toxic potential or allergenic properties. The panel indicated that compounds with immediate toxic effects should be the highest priority in terms of monitoring.

#### **3.5.6 Biological Monitoring**

Careful analysis of biological samples before and after a stay on SSF may give valuable clues to adverse exposure. Postflight analysis of blood cells for the formation of hemoglobin or DNA adducts during a space mission could be used to indicate whether significant exposure to biologically active electrophilic compounds has occurred. Analysis of urine or hair would be particularly valuable in terms of assessing exposure to metals.

#### **3.5.7 Analysis of Contaminant Data**

A data downlink to a ground-based environmental health console should be provided for routine analysis of complex data and to deal with any emergency contamination situations. During nominal operations, data from

compound-specific analyzers, the total hydrocarbon analyzer, and the volatile organic analyzer should be stored and later downlinked at a convenient time. However, when SSF is occupied initially, one of the crewmembers should be trained in environmental health monitoring. It would be expected that this crewmember could interpret much of the monitoring data. When instruments are operated in a portable mode, data logging capability should be available with provision for transfer to the SSF data management system. Finally, the panel recommended real-time downlinking of emergency monitor responses during a chemical-contamination incident, so that decisions on inhalation hazards to crewmembers may be made in a timely fashion.

#### 3.5.8 Instrumentation Technologies

The panel members recommended that the environmental health instrument cluster be designed to accommodate newly developed monitoring equipment such as second generation monitors or new technologies. Current technologies appropriate for analysis of specific compounds include: Fourier transform and photoacoustic infrared detectors; ion mobility spectrometry; gas chromatography; and ion-specific electrodes. Technologies identified for a total hydrocarbon analyzer (THA) were photoionization, catalytic surface detectors or ion-mobility spectrometry. The volatile organic analyzer involves complex instrumentation; however, several technologies were identified: gas chromatography/mass spectrometry; ion trap mass spectrometry (MS/MS) with a glow-discharge source; gas chromatography/ion mobility spectrometry; and correlation gas chromatography. Promising future technologies include fiber optics and microchips that measure heat of formation for quantitation of specific compounds.

## SECTION 4

### ACRONYMS AND ABBREVIATIONS

CEGL	Continuous Exposure Guidance Level
ECLSS	Environmental Control and Life Support System
EEGL	Emergency Exposure Guidance Level
EMAC	Emergency Maximum Allowable Concentration
IDLH	Immediately Dangerous to Life or Health
NRC	National Research Council
OSHA	Occupational Safety and Health Administration
SMAC	Spacecraft Maximum Allowable Concentration
SSF	Space Station Freedom
STEL	Short-Term Exposure Limits
STS	Space Transportation System (Shuttle)
THA	Total Hydrocarbon Analyzer